Diagnosing Energy Loss: PHENIX Results on High-p_T Hadron Spectra

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Abstract. Measurements of inclusive spectra of hadrons at large transverse momentum over a broad range of energy in different collision systems have been performed with the PHENIX experiment at RHIC. The data allow to study the energy and system size dependence of the suppression observed in R_{AA} of high-p_T hadrons at $\sqrt{s_\mathrm{NN}}$= 200 GeV. Due to the large energy range from $\sqrt{s_\mathrm{NN}}$= 22 GeV to 200 GeV, the results can be compared to results from CERN SPS at a similar energy. The large Au+Au dataset from the 2004 run of RHIC also allows to constrain theoretical models that describe the hot and dense matter produced in such collisions. Investigation of particle ratios such as η /π^0 helps understanding the mechanisms of energy loss.

1. Introduction

Previous measurements at RHIC have shown a significant suppression at high p_T of π^0, η , and charged hadrons in central Au+Au collisions at $\sqrt{s_\mathrm{NN}}$= 200 GeV compared to binary scaled p+p collisions [1, 2]. This suppression was found to be p_T -independent for $p_\mathrm{T} > 5$ GeV/c [3]. A suppression of R_{AA} has also been observed in the smaller Cu+Cu collision system, being similar in amount for similar numbers of participants [3].
Possible initial state effects have been studied by measuring π^0 production in d+Au collisions and investigating a centrality dependence in such collisions. These effects have been found to be small [4], thus the suppression in Au+Au is attributed to final state interactions such as gluon radiation of partons in hot dense matter.
To shed further light on the mechanism of energy loss, the energy dependence of the suppression can be studied with a variety of data as RHIC delivers collision energies over a broad range from $\sqrt{s_\mathrm{NN}}$= 22.4 GeV which is close to SPS energies, up to $\sqrt{s_\mathrm{NN}}$= 200 GeV. Improved analysis methods and better statistics also lead to a better understanding of energy loss using high-p_T hadron spectra.

‡ For the full list of PHENIX authors and acknowledgements, see Appendix 'Collaborations' of this volume

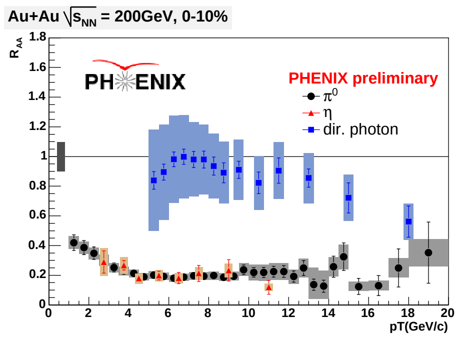

Figure 1. Nuclear modification factor R_{AA} for π^0 [3] and η mesons in comparison with direct photons [5] in 0-10% most central Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$= 200 GeV. The error bars show the p_{T} uncorrelated errors, the boxes around the points show the p_{T} correlated errors, the box at the left shows the normalization uncertainty.

2. Spectra measurement and R_{AA}

The PHENIX experiment measures π^0 and η mesons via their two-photon-decay. The decay photons are measured with the Electromagnetic Calorimeter, consisting of two sectors of lead glass and six sectors of lead scintillator sandwich calorimeters, at midrapidity. Each sector covers 22.5 degrees in azimuth. Uncorrected particle yields are extracted with an invariant mass analysis using event mixing for background subtraction. They are then corrected for different effects such as the detector acceptance and the reconstruction efficiency [1, 4, 6].

The nuclear modification factor R_{AA} is shown in Fig. 1 for η mesons in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$= 200 GeV in comparison with R_{AA} for π^0 [3] and direct photons [5]. The suppression of both mesons appears to be the same which can be explained with partonic energy loss in the medium. The direct photons show an indication for suppression at $p_{\mathrm{T}} > 14$ GeV/c. This is consistent with initial state effects [5].
The energy dependence of R_{AA} is examined in Cu+Cu collisions, where the π^0 R_{AA} has been measured at three different energies ($\sqrt{s_{\mathrm{NN}}}$= 200 GeV, 62.4 GeV, and 22.4 GeV), shown in Fig. 2a for the most central events. The suppression is strongest at high energies, $R_{AA} \sim 0.4$ at $\sqrt{s_{\mathrm{NN}}}$= 200 GeV, while towards lower energies, a Cronin like enhancement at $p_{\mathrm{T}} < 5$ GeV/c becomes clearly visible. Compared to Pb+Pb data from the WA98 experiment at CERN, measured at $\sqrt{s_{\mathrm{NN}}}$= 17.2 GeV, the 22.4 Cu+Cu R_{AA} is similar for similar N_{part} as shown in Fig. 2b. At this low energy, PHENIX has observed no significant centrality dependence of the shape of the π^0 spectra (not shown).

3. η/π^0 Ratio

Fig. 3a shows the η /π^0 ratio for Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$= 200 GeV for different centrality selections in comparison with a PYTHIA [9] calculation and in Fig. 3b for Cu+Cu collisions at $\sqrt{s_{\mathrm{NN}}}$= 62.4 GeV. The ratio is found to be independent of centrality over the whole p_{T} range and the PYTHIA curve is in good agreement with the measured data. The ratio does not show a system size or energy dependence and is consistent with data from earlier measurements at different energies and collision systems [6]. A possible explanation is that the suppression of high-p_{T} hadrons occurs at the partonic level and that the fragmentation is not affected by the medium.

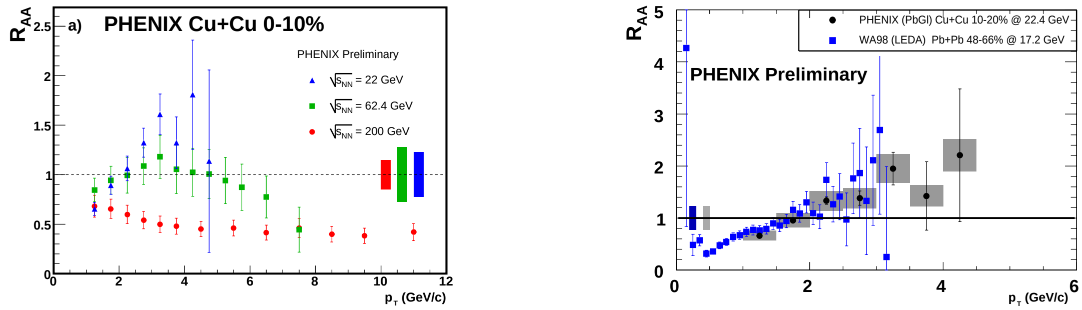

Figure 2. a) π^0 R_{AA} for the 0-10% most central Cu+Cu collisions at $\sqrt{s_{\mathrm{NN}}}$= 200 GeV, 62.4 GeV, and 22.4 GeV. b) π^0 R_{AA} for 10-20 % most central Cu+Cu (N_{part} = 67.8, $\sqrt{s_{\mathrm{NN}}}$= 22.4 GeV) from PHENIX and for 48-66 % most central Pb+Pb (N_{part} = 63, $\sqrt{s_{\mathrm{NN}}}$= 17.2 GeV) from WA98 [7, 8]. The error bars are of the same type as in Fig. 1.

4. Constraining Model Parameters

There are different theoretical models describing the observed suppression of R_{AA} at $\sqrt{s_{\mathrm{NN}}}$= 200 GeV. These models describe the suppression as function of the initial gluon density dN/dy [10, 11] or the medium transport coefficient <q̂> [12]. Both the PHENIX measurement of the nuclear modification factor in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$= 200 GeV and theoretical predictions for different values of the parameter dN/dy are shown for one example [10] in Fig. 4a. The data can be used to constrain these theoretical parameters. For this both the correlated and the uncorrelated errors of the measurement are taken into account in a χ^2 analysis. For each value of the theory parameter, in a first step the data points are varied within 4 RMS of the correlated errors to find the most probable variation, taking the probability for both the offset and the point-by-point deviation into account. In a second step, the probabilities for numerous randomly chosen combinations of both error types are calculated. The p-value is then defined as the fraction of these variations that are less probable than the variation found in step one, so p-value < 1. The probabilities for different parameter choices are eventually calculated as $1-$p-value, they are shown in Fig. 4b, c, and d.

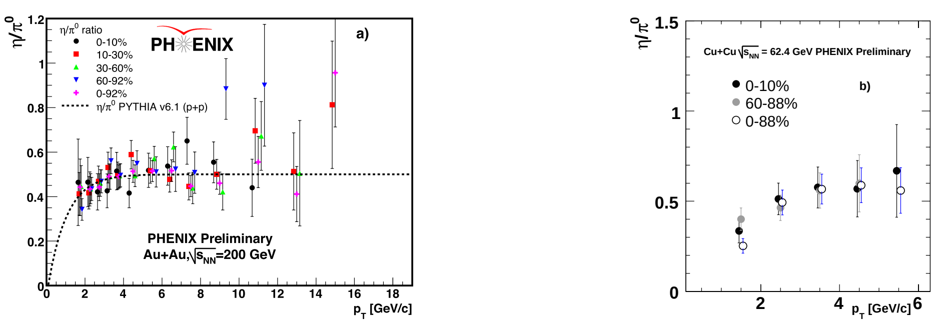

Figure 3. Ratio of η and π^0 a) in Au+Au at $\sqrt{s_{\mathrm{NN}}}$= 200 GeV for different centrality selections in comparison with a PYTHIA [9] calculation and b) in Cu+Cu at $\sqrt{s_{\mathrm{NN}}}$= 62.4 GeV. The error bars show the total errors.

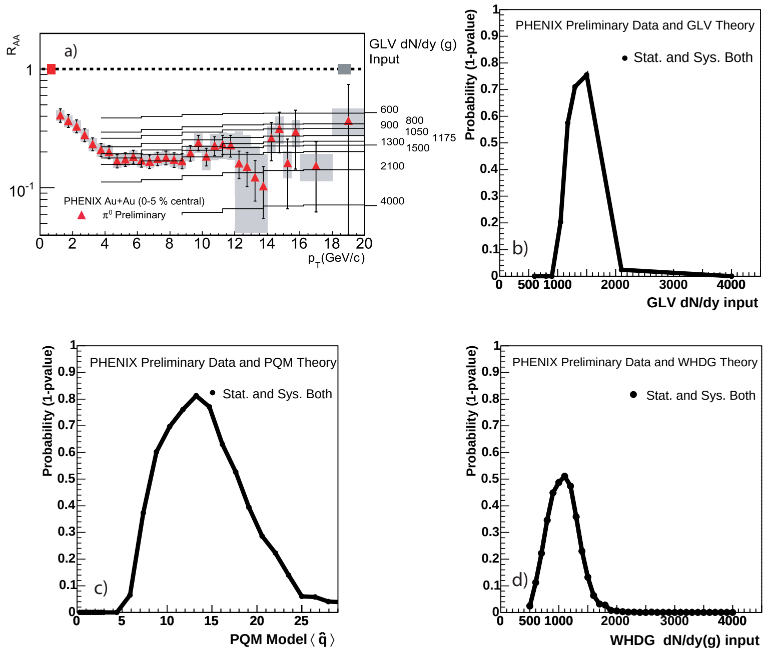

Figure 4. a) π^0 R_{AA} in Au+Au at $\sqrt{s_{\rm NN}}$= 200 GeV compared with predictions from a theoretical model [10] for different values of the initial gluon density dN/dy. b) $1-$ p-value for certain values of dN/dy in GLV model. c) $1-$ p-value for certain values of medium transport coefficient <q̂> in PQM model [12]. d) $1-$ p-value for certain values of dN/dy in WHDG model [11].

5. Summary

The PHENIX experiment has measured π^0 and η mesons over a broad range of energies in different collision systems. The nuclear modification factor of both mesons, which are suppressed by the same factor, can be described with models explaining this suppression with partons losing energy in the hot and dense medium. The suppression shows an energy dependence and becomes strongest at higher collision energies.

The production ratio $\eta\ /\pi^0$ is the same for different collision systems and energies. It is unaffected by medium effects in different collision systems. This observation supports the assumption of partonic energy loss and fragmentation outside the medium.

The experimental data have been used to constrain the parameters of different theoretical models. This is a first step to use the data for more quantitative statements. However, the large uncertainties limit the discriminative power of the comparison.

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